STEAM ENGINE WATER RATES

...BY...

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THESIS

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STEAM ENGINE WATER RATES.

INTRODUCTORY OUTLINE.

In the following thesis a discussion is presented on the economic usage of steam in the reciprocating engine, together with the several conditions effecting such usage. The subject has been sub-divided and is presented under the following heads:-

1. Method of measuring engine performance;
2. Theoretical engine performance;
3. Tables of theoretical performance;
4. Object of the tests made by the writer;
5. Tests of Meyer 8 in.x 12 in. automatic engine U of I shops;
    - a Description of engine;
    - b Steam supply;
    - c Methods employed in making test;
    - d Description of apparatus used;
    - e Computation and results;
6. Tests of Ball 8 in.X 10 in. automatic engine U of I shops.

STEAM ENGINE WATER RATES.

REFERENCE TO TABLES AND CURVES.

STEAM ENGINE WATER RATES.

Method of Measuring Engine Performance:-

The introduction and developopments of the steam-engine indicator has lead to an accurate and scientific determination of engine performance. The performance of an engine is measured in pounds of water consumed per indicated horse power per hour (English units). These units are absolute for any given pressure under which water is converted into steam. But the thermal value of a pound of steam varies as the pressure, and increases as the pressure increases. However the values obtained for the different steam preassures can be standardized and compared by reducing to the equivalent evaporation from and at 212°Fah. i.e.from water at 212° Fah. to steam under steam under atmospheric pressure. This is rarely done except in the determination of boiler performance. This method of comparing and determining engine performance has been universally adopted by engineers and engine builders, who during the past twenty years have compiled and published much valuable data on the subject.

Theoretical Engine Performance:-

Tables giving the water rates of the perfect steam-engine were the first to appear. In the deduction of these tables the assumption was made that no loss of heat took place during the expansive working of the steam, i.e.,that there was no loss due to radiation. These tables give the consumption that may be expected for different initial and final pressures, as well as different points of cutt-off. Such tables have been derived by various authors by the application of the principles of Thermodynamics. It may be well before going further to review the method of deduction of these tables.

If we denote the delivery of work in foot-pound of any engine (L) we have the equation $L=\frac{Q(T-T)}{A\ T}$ in which (Q) equals total heat imparted to the feed-water;(T)equals absolute temperature of steam corresponding to initial pressure reconed from 459.4 degrees below zero Fah.; (T) equals absolute temperature corresponding to final pressure; (A) equals thermal equivalent of one unit of work, equals $\frac{1}{778}$, (English units). Now for (Q) the value, G (q rx-q)may be substituted in which (G) equals number of pounds of steam and water used; (q)equals heat in one pound of the liquid at the temperature of the steam; (r) equals latent heat of vaporization; (x) equals weight of steam in one pound of the mixture, equals quality of steam; (q) equals heat in one pound of the feed-water. This value of (Q) gives for (L)

$$L=\frac{G(q\ rx-q\ )(T-T)}{A\ T}$$

and the delivery of the engine for one pound of steam equals L÷G foot-pounds. And the number of pounds of steam (G) of quality (x) necessary to give a certain delivery (L), is

$$G=\frac{L(AT)}{(q\ rx-q)(T-T)}$$

If we assume the delivery (L) to be one horse-power for one hour equals 33000x60=1980000 foot-pounds, we find

$$G=\frac{1980000\ x\ AT}{(q\ rx-q\ )(T-T)}$$

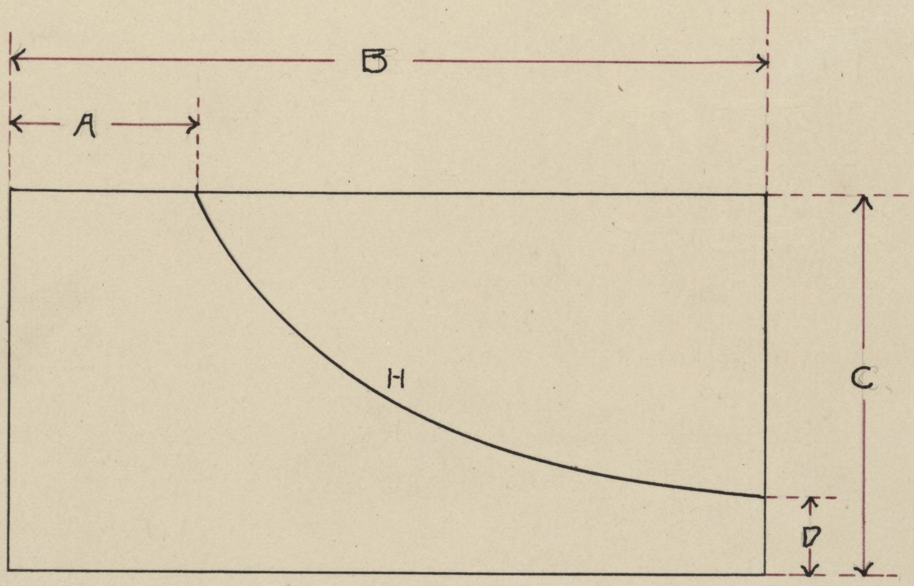
In this formula (A) is known, (q), (r) and (T) can be taken from standard steam tables, (q) and (x) may be assumed, (T)the final temperature depends upon (T) the temperature corresponding to the steam pressure and the ratio of expansion. It may be found as follows: Take some rectangle of units length and let the sides equal length of stroke and the height equal initial pressure drawn to some convenient scale, and on the upper line lay off from the left the per cent cut-off. From this point of cut-off plot by any convenient method the adiabatic expansion curve to the end of the rectangle. The ordinate of this curve at the end of the rectangle will give the final pressure, and from a standard steam table the corresponding temperature (T) may be found. This final pressure can be found also by the use of logarithms from the formula PV = PV where (P) and (V) are respectively initial pressure and initial volume and (v) is final volume. It is clear that from the above the number of pounds of water (G) necessary to produce one horse power for one hour can be determined for every cut-off or any initial pressure. It is interesting to note that the difference in the values of (G) for the different cut-offs is due to change in (T) it being the only factor that changes for the different expansions.

Tables of Theoretical Engine Performance:-

A table of water rates computed by the above method is given on page Other tables have been published from time to time showing very nearly what water rates may be expected from first class engines. These are based on theoretical computations. The values in these tables are of course greater than those in the theoratical and are inversely proportional to unity and the assumed efficiency of the working substance. At present there is a fair amount of available data showing the actual performance of steam engines of different kinds working under different conditions. This material

GRAPHICAL METHOD OF DETERMINING FINAL TEMPERATURE - ASSUMED CASE.

SCALE 1" = 40#



A = CUT OFF = .25 STROKE
B = LENGTH OF STROKE
C = BOILER PRESSURE = 80#
D = FINAL " = 16#
T. = COR. TEMP. = 216.34
H = PV CURVE. SEE KLEINS H.S. ENGINE, pp. 13.

WATER RATES, LB. PER I.H.P. PER HR. FOR 75 LB. INITIAL PRESSURE
BEST CONDITIONS

NON CONDENSING, AUTOMATIC CUT OFF				CONDENSING, AUTOMATIC CUT OFF			
CUT OFF PER CENT STROKE	M.E.P.	FINAL PRESSURE ABSOLUTE	WATER CONSUMPTION	CUT OFF PER CENT STROKE	M.E.P.	FINAL PRESSURE ABSOLUTE	WATER CONSUMPTION
10	16.04	10.52	27.8	10	28.04	10.52	18.5
15	24.92	14.86	25.3	15	36.92	14.86	19.3
20	32.32	19.31	24.9	20	44.32	19.31	19.9
25	38.72	23.73	25.2	25	50.72	23.73	20.6
30	44.35	28.07	25.6	30	56.35	28.07	21.5
35	49.05	32.47	26.2	35	61.05	32.47	22.4
40	53.27	36.82	27.1	40	65.27	36.82	23.0
50	60.25	45.61	27.9	50	72.25	45.61	24.7
THEORETICAL				THEORETICAL			
10	16.04	10.52	19.7	10	28.04	10.52	13.0
15	24.92	14.86	18.8	15	36.92	14.86	14.1
20	32.32	19.31	19.1	20	44.32	19.31	15.0
25	38.72	23.73	20.4	25	50.72	23.73	16.1
30	44.35	28.07	21.0	30	56.35	28.07	17.0
35	49.05	32.47	21.8	35	61.05	32.47	18.1
40	53.27	36.82	22.6	40	65.27	36.82	18.8
50	60.25	45.61	24.5	50	72.25	45.61	21.0

is largely in form of reports published in the different engineering periodicals, and in the proceedings of the engineering societies.

On page 7 is given a table for both condensing and noncondensing automatic cut-off engines. The tables show the most economical rate of expansion to be about 20 per cent for the noncondensing and 15 per cent for the condensing. But this is true so far as the indicator is effected only, for there are losses not accounted for by the indicator such as friction, radiation and initial condensation, which losses become less as the rate of expansion increases, to a certain degree. Taking these things into account the most economical point of cut-off would in this case be 6 per cent higher. It is clear that all these corrections are implied when water rates are given in terms of brake horsepower.

The table for high speed noncondensing automatic cut-off engines given on page 9 shows the water consumption both actual and indicated per indicated horsepower. It is to be noticed that for the best rate of expansion, the high speed automatic cut-off uses a little less water than the low speed given on page 7. In all these tests the steam pressure was 75 pounds guage. The rates given on page 9 for throttling engines show that a little more steam is necessary to operate this class, and the indicated rate of expansion for best economy is a little later than for the automatic. These tables were chosen for copy because they give about the average result of tests made in engines of the different types.

In all these tests the conditions of operation were made to be as nearly perfect as possible. This is usually done in tests of th this kind, and as a result we find more data relating to best

TABLES OF WATER RATES

CUT OFF PER CENT STROKE	M.E.P.	TERMINAL PRESSURE	INDICATED-RATER LB. PER I.H.P. PER HR.	ACTUAL WATER PER I.H.P. PER HR.
10	HIGH SPEED NON CONDENSING AUTOMATIC CUT OFF (BUCKEYE C°)			
15	18	11	20	32
20	27	15	19	27
25	35	20	19	25
30	42	25	20	25
35	48	30	20	24
40	53	35	21	25
45	57	38	22	26
50	61	43	23	27
	64	48	24	27

MEDIUM SPEED THROTTLING (THURSTON)
WATER PER I.H.P. PER HOUR

STEAM PRESSURE	RATIO OF EXPANSION					
	2	3	4	5	7	10
30	40	39	40	40	42	45
45	35	34	36	36	38	40
60	30	28	27	26	30	32
75	28	27	26	25	27	29
90	26	25	24	23	25	27
105	25	24	23	22	22	21
135	24	23	22	21	20	20

practice in steam engineering, than to the performance of engines operated under the less favorable condition to which they may be subjected. It is an established fact that a great many engines in continuous use are operated extravagantly. This can be detected in many cases by observation, but even then the exact knowledge of the real waste would cause surprise.

Object of Tests Made by the Writer:-

Considering the facts mentioned above the writer concluded to make a series of tests of engines to determine water rates, in which the conditions of operation should not be altered in any way from those to which the engines had been subjected in every day use. Two engines were tested for water rates. They were the 8 in. x 12 in. Meyer engine of the Mechanical Laboratory of the University of Illinois. And the 8 in. x 10 in. Ball engine used to furnish power for the University shops.

TESTS OF MEYER ENGINE 8 IN. X 12 IN.

Description of Engine:-

This is a high speed, noncondensing automatic cut-off engine of the side crank pattern. The general outline is shown in plate 1. The valve gear is controlled by weighted pendulum governor. The engine was used from time to time by classes in the Mechanical Engineering Laboratory and was out of adjustment in almost every pair. The crank shaft was out of line and caused the main bearings to run hot. A great amount of undue friction was caused by tight piston packing. And the valve gear was loose in several boxes. Notwithstanding this state of affairs, the engine ran with little noise and gave no trouble, though the mechanical efficienty was very low.

Steam Supply:-

The engine was supplied with steam by a forty horse power horizontal tublar boiler. About eighty feet of unjacketed 2.5 in. pipe connected the two. The exhaust was allowed to flow through thirty five feet of 3 in. pipe, to the atmosphere.

Method Employed In Making Test:-

Steam distribution was obtained by the use of two 2 in. Tabor indicators fitted with a reducing motion of the pendulum type. Power was absorbed at the rim of the fly wheel by a common rope brake, resting on a pair of platforn scales. The brake was kept cool by a constant flow of water, from the city water pipe. Revolutions per minute were read directly from a tachometer belted to the crank shaft. Quality of steam was taken at the steam pipe a few feet above the throttle by a carpenter separating calorimeter.

Clearance space was determined as follows: the piston valve was removed and a pine wood plug turned to fit the valve chamber tightly. The engine was then brought to dead centre, and water was poured into the cylinder through the indicator cock, until it was full. A line was scribed on the crosshead, and on the guides opposite, the engine was moved off centre and the same amount of water as was first used, was added, the engine was then turned back until water appeared at the cock, when another line was scribed on the guides opposite the one on the crosshead. The distance between marks on the guides gave the clearance in part of stroke, or in piston displacement. In order to be able to set the engine at any desired cut-off, the valve gear was calibrated and a curve deduced which gives cut-off in terms of valve travel. From this curve the valve travel necessary to give a certain cut-off, can be found, and then the brake load adjusted to give this valve travel. The determination was as follows: the engine was taken cold and the governor blocked at different positions which it takes within its working limit. With the governor blocked in one of these positions, the engine was brought to dead centre and a line scribed on the crosshead and on the guides opposite. The engine was then turned off centre and moved ahead till the point of cut-off was reached. This point was easily determined by observation, the steam chest cover having been removed. With the engine in the position of cut-off another line was scribed on the guide opposite the one on the cross head, and the distance between this mark and the one while the engine was on dead centre gave the cut-off in part stroke. This was done for both head and crank ends and for several positions of the governor. To find the valve travel in each case, a pencil was clamped to the valve rod and allowed to scribe on a fixed card while the engine was being turned over. The data obtained is given on page 14 and the results on page 20. From these results together with per cent clearance, the curves on page 15 were deduced. The ordinates are in inches of valve travel and the abscissae give the per cent cut-off. The upper curve is for part stroke and the lower for real cut-off i.e., for part stroke plus clearance. For example: if the valve travel is 1.5 in., the cut-off in per cent stroke is about nineteen, while for real cut-off it is about twenty six.

The amount of water used during the test was measured by a

STEAM ENGINE WATER RATES

LOGS OF TESTS ON MEYER AUTOMATIC ENGINE 8" × 12"

TIME	R.P.M. BY TACH-OMETER	BOILER PRES.	WATER GAGE	VALVE TRAVEL	BRAKE LOAD LB.	TIME	R.P.M. BY TACH-OMETER	BOILER PRES.	WATER GAGE	VALVE TRAVEL	BRAKE LOAD LB.
TEST-1. 1-18-98						TEST-4. – 1.24.98.					
3:00	256	75	6.9"	1.2"	0	3:10	255	80	6.50	1.37"	24.5
3:20	255	83		"	"	3:25	255	85		"	"
3:30	257	81	4.85	"	"	3:35	250	85	4.50	"	"
						3:40	255	80		"	"
					"					"	"
3:45	257	80	3.75	"	"	3:50	253	85	3.20	"	"
TEST-2. 1-18-98.						TEST. 5. 1-24-98.					
4:00	252	78	5.80	1.37"	24.5	4:15	245	80	6.90	1.62"	95
4:16	263	75	4.75	"	"	4:25	250	90	5.83	"	"
4:20	262	75		"	"	4:40	250	85		"	"
4:25	262	78		"	"	4:45	250	85	3.90	"	"
				"	"	4:55	250	80	2.80	"	"
4:30	262	80	3.70	"	"						
TEST-3. 1-24-98.						TEST-6. 1-27-98.					
2:15	256	80	5.9	1.2"	0	2:25	251	85	4.80	1.50	70
2:20	256	80		"	"	2:30	252	85		"	"
2:30	258	80	4.85	"	"	2:35	253	80	3.90	"	"
2:35	258	85		"	"	2:40	253	75		"	"
2:40	258	85		"	"	2:45	250	75		"	"
2:45	260	85	4.05	"	"	2:55	253	80	2.98	"	"

STEAM ENGINE WATER RATES

LOGS OF TESTS ON MEYER AUTOMATIC ENGINE 8"x12"

TIME	R.P.M. BY TACHOMETER	BOILER PRES.	WATER GAGE	VALVE TRAVEL	BRAKE LOAD
TEST-7. 1-27-98.					
3:25	250	80	7.10	1.62"	95
3:30	253	82		"	"
3:35	256	80	5.65	"	"
3:40	252	78	4.20	"	"
3:55	—		"	"	"
					"
TEST. 8.- 1-28.98.					
2:25	252	80	7.2	1.80"	130
2:38	242	75		"	"
2:45	246	78	5.10	"	"
2:53	241	82		"	"
				"	"
2:55	252	82	2.77	"	"
TEST-9. 1-28-98.					
3:20	228	78	9.00	2.12	220
3:30	228	80		"	"
3:35	229	78	5.40	"	"
3:40	229	77		"	"
3:45		76		"	"
3:50	228		1.75	"	"

LOG OF CALIBRATION OF VALVE GEAR 1-6-98.

EX. No	CUT OFF — HEAD	CRANK	MEAN	VALVE TRAVEL
1	7.00"	7.50"	7.25"	2"
2	5.60"	6.37	5.98	1.87"
3	4.55"	5.35"	4.95	1.75"
4	3.62"	4.37"	4.00	1.62"
5	3.35"	3.12"	3.23	1.50"

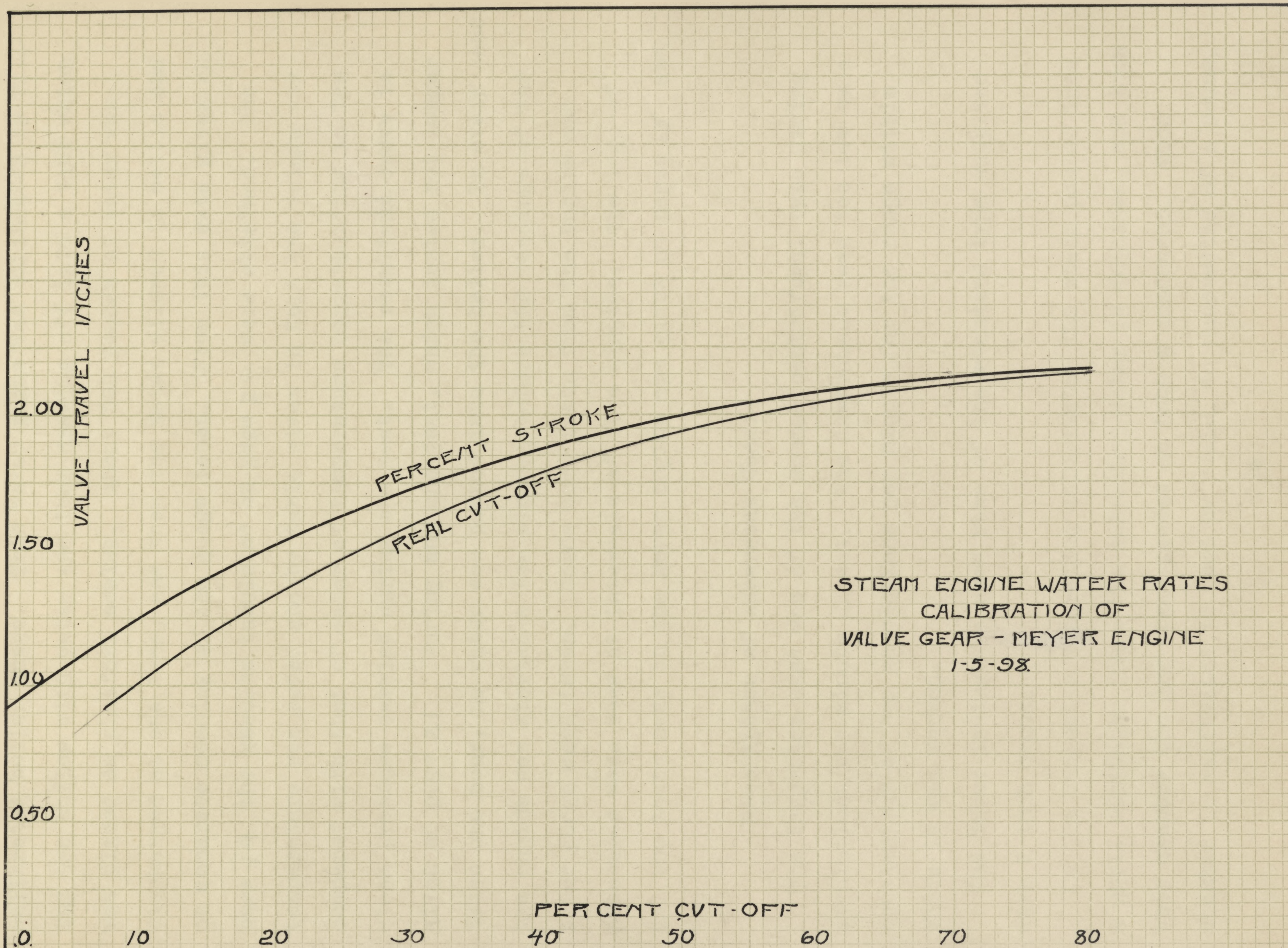
LOG. CALIBRATION BOILER No 3. AT U. OF I. SHOPS. 2-26-98. TEMP. H_2O=125°F.

WATER IN GAGE	WATER DISCHARG'D	WATER IN GAGE	WATER DISCHARGED
9.65"	0 LB	3.65"	1050 LB.
7.85"	250. "	2.35"	1350 "
6.15"	550. "	1.45"	1550 "
4.85"	800. "	.80"	1700 "

LOG CALORIMETER TESTS FROM STEAM PIPE 1-24-27-98.

READING BOILER GAGE	CONDENSED STEAM	ENTRAINED WATER
2"	2 LB.	.18 LB
4"	"	" "
8"	"	.14 "
5"	"	.21 "
3"	"	.22 "

14


VALVE TRAVEL INCHES
2.00
1.50
1.00
0.50
PERCENT STROKE
REAL CUT-OFF
STEAM ENGINE WATER RATES
CALIBRATION OF
VALVE GEAR - MEYER ENGINE
1-5-98.
PER CENT CUT-OFF
.0.
10
20
30
40
50
60
70
80

calibrated boiler guage. This water gague was calibrated by filling the boiler with water and then drawing off into a tank which was placed on platforl scales. About 250 pounds of water was discharged at one time, and then the water allowed to settle and an accurate reading of the guage taken. From this data given on page 14 the results tabulated on page 20 were obtained. The temperature was noted and by table given in Kent the volume was compared with that of water at temperature corresponding to the steam pressure carried during the test. The resultant curve is given on page 21. During any one teat, which lasted not longer taken one hour, no water was pumped into the boiler. In every case the engine was started a few minutes before the readings of the water guage were taken. Cards were taken from the engine and pressures were read at intervals of five minutes. The logs of all the tests made on the Meyer engine are given on pages 13 and 14.

Description of Apparatus Used:-

The tachometer used was of the common centrifugal type giving revolutions per minute direct. The instrument read too low by a constant of of ten revolutions per minute for the range within which it was worked.

The Tabor indicators used were of the standard type supplied with 2 inch drums.

In the carpenter separating calorimeter the steam passes into a small separator where the entrained water is detained, and from this chamber the dry steam passes on into a condenser. Each chamber is calibrated to read by scale, to hundredths of a pound.

STEAM ENGINE WATER RATES
RESULTS OF TESTS ON MEYER ENGINE

CARDS No	REV. PER. MIN.	INITIAL PRESSURE	FINAL PRESSURE	IND. HORSE POWER	BRAKE HORSE POWER	CUT OFF PER CENT STROKE + CL'R'NCE	WATER PER HOUR	WATER PER I.H.P. PER HOUR	WATER PER B.H.P. PER HOUR	
				EXPERIMENT No 1.						
1	266.	58.5	7.5	7.38	—	15	646.6 POUNDS	75.09 POUNDS	— . — . —	
2	266.	83.5	13.5	8.97	—	"				
3	265.	77.5	13.	7.55	—	"				
4	266.	77.5	14.5	10.57	—	"				
MEAN	265.7	74.2	12.1	8.61	—	"				
				EXPERIMENT No 2.						
5	262.	75.	15.	11.00	2.79	20	695.4 POUNDS	64.21 POUNDS	248.4 POUNDS	
6	263.	75.	15.	10.84	2.80	"				
7	263.	74.	11.5	9.26	2.80	"				
8	263.	78.	14.	12.23	2.80	"				
MEAN	262.8	75.5	13.9	10.83	2.79	"				
				EXPERIMENT No 3						
9	266.	81.	14.	7.04	—	15	585.6 POUNDS	77.6 POUNDS	— . . — . . —	
10	268.	80.	11.5	7.10	—	"				
11	268.	78.	12.5	6.91	—	"				
12	268.	77.	13.	8.14	—	"				
MEAN	267.5	79.	12.7	7.54	—	"				

STEAM ENGINE WATER RATES
RESULTS OF TESTS ON MEYER ENGINE

CARDS Nº	REV. PER. MIN.	INITIAL PRES.	FINAL PRES.	IND. HORSE POWER	BRAKE HORSE POWER	CUT OFF PERCENT STROKE +CL'R'NCE	WATER PER HOUR	WATER PER I.H.P. PER HOUR	WATER PER B.H.P. PER HOUR
EXPERIMENT Nº 4.									
13	265	76	13	11.09	2.83	20	779.58 POUNDS	73.67 POUNDS	278 POUNDS
14	265	81	13.5	9.50	2.83	..			
15	260	74	13.5	10.95	2.75	..			
16	262	82	15.5	10.79	2.79	..			
MEAN	263	80.7	13.87	10.58	2.80	..			
EXPERIMENT Nº 5.									
17	265	80.	14	17.46	10.98	30	988.2 POUNDS	51.62 POUNDS	93.22 POUNDS
18	260	84.	17	19.60	10.47	..			
19	260	85.	18	18.59	10.47	..			
20	260	80.	17	20.90	10.47	..			
MEAN	261.2	82.25	16.5	19.13	10.59	..			
EXPERIMENT Nº 6.									
21	261	77.5	16.5	16.24	7.96	25	622.2 POUNDS	41.83 POUNDS	78.76 POUNDS
22	263	75.	14.5	13.21	8.00	..			
23	263	70.	14.5	15.78	8.00	..			
24	260	79.	16.	14.27	7.64	..			
MEAN	261.2	75.4	14.9	14.87	7.90	..			

STEAM ENGINE WATER RATES
RESULTS OF TESTS ON MEYER ENGINE

CARDS No	REV. PER. MIN.	INITIAL PRES.	FINAL PRES.	IND. HORSE POWER	BRAKE HORSE POWER	CUT OFF PER CENT STROKE +CLR'NCE	WATER PER HOUR	WATER PER I.H.P. PER HOUR	WATER PER B.H.P. PER HOUR
EXPERIMENT No 7									
25	261	76.5	17.5	19.14	10.58	30	887.5 POUNDS	46.78 POUNDS	84.12 POUNDS
26	263	69.	16.5	19.65	10.83	〃			
27	263	63.5	16.5	18.75	10.83	〃			
28	260	62.	15.5	18.37	10.49	〃			
MEAN	261.2	67.7	16.5	18.97	10.55	〃			
EXPERIMENT No 8									
29	255	78.5	20.5	21.75	14.89	40	1424.14 POUNDS	62.09 POUNDS	98.21 POUNDS
30	252.	70.5	19.	22.10	14.32	〃			
31	256	71.5	17.	22.38	14.95	〃			
32	251	82.	22.	23.75	14.27	〃			
MEAN	253.2	75.6	19.6	22.49	14.50	〃			
EXPERIMENT No 9									
33	238	69.	33.	31.88	22.67	70	2247. POUNDS	71.0 POUNDS	99.7 POUNDS
34	238	72.	33	31.00	22.67	〃			
35	239	71.	32	32.01	22.71	〃			
36	239	72.5	33	31.74	22.71	〃			
MEAN	238.5	71.1	32.7	31.66	22.69	〃			

STEAM ENGINE WATER RATES
RESULTS OF TESTS AND CALIBRATIONS – MEYER ENGINE

CALIBRATION OF VALVE GEAR. – TABLE. 1

VALVE TRAVEL	MEAN CUT OFF	PER C'T STROKE	PER CENT STROKE +CLEARANCE.	TABLE FROM CURVE – REAL CUT OFF	VALVE TRAVEL
2." 0"	7.25"	60.3	55.7	20 %	1.37"
1.87"	5.98"	49.6	45.8	25 "	1.50"
1.75"	4.95	40.2	37.2	30 "	1.61"
1.62"	3.50	33.3	30.8	40 "	1.79"
1.50"	3.40	27.5	25.43	50 "	1.94"
				60 "	2.05"
				70 "	2.11"

CALIBRATION OF BOILER – TABLE. 2

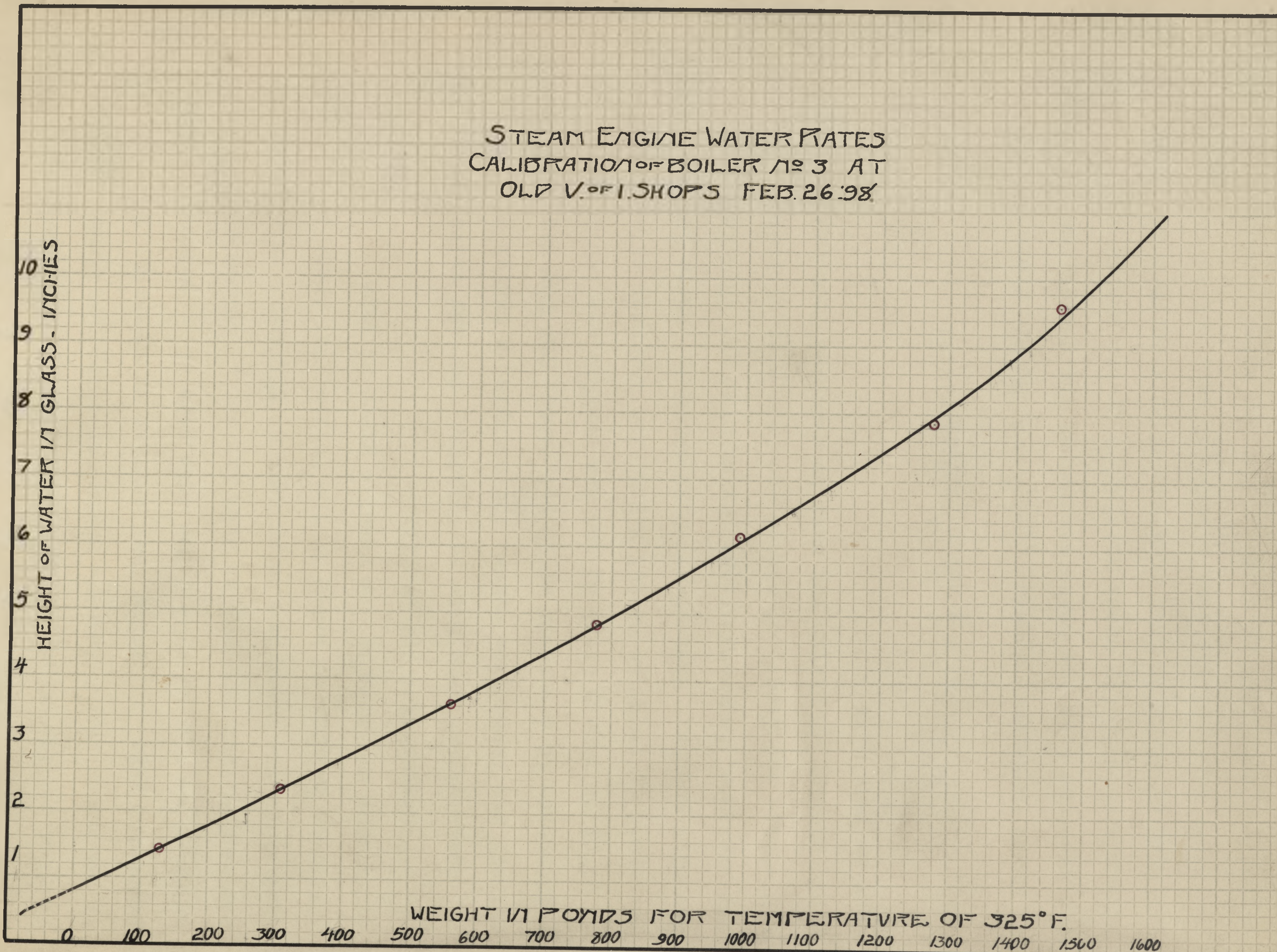
GAGE READING	WATER IN BOILER. .8" GAGE, AS O	VOL. OF WATER	WATER IN BOILER AT 80 LB. P.
9.56"	1700 LB	26.0 CU FT	1463. LB
7.85"	1450 "	22.18 "	1279.2 "
6.15"	1150 "	17.57 "	990.3 "
4.85"	900 "	13.77 "	776.25 "
3.65"	650 "	9.94 "	559.62 "
2.35"	350 "	5.35 "	301.20 "
1.45"	150 "	2.29	128.90 "
.80"	0 "	0.0	0.0 "

CALORIMETER TEST. TABLE 3

BOILER GLASS GAGE READING	PER CENT WATER	EX. No	BOILER GLASS GAGE READING	PER CENT WATER	EX. No
2"	8.25	1	5"	9.50	4
4"	8.25	2	3"	9.90	5
8"	6.54	3		8.50	MEAN

WATER RATES MEAN RESULTS

CUT OFF	INITIAL PRES.	FINAL PRES	WATER PER I.H.P. PER HR	WATER PER B.H.P. PER HR
15 %	78	12	76	–
20 "	78	13	68	268.
25 "	75	15	42	79.
30 "	75	18	49	89.
40 "	76	19	62	98.
50 "	78	15	67	
60 "	78	15	70	
70 "	78	15	71	


STEAM ENGINE WATER RATES
CALIBRATION OF BOILER No 3 AT
OLD U. OF I. SHOPS FEB. 26 '98
HEIGHT OF WATER IN GLASS. INCHES
WEIGHT IN POUNDS FOR TEMPERATURE OF 325° F.
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600
1 2 3 4 5 6 7 8 9 10

21

To find quality of steam, let W= weight of condesned steam, as read on condenser gage. Let W'= amount of entrained water indicated by separator gage, as having been carried by steam W. Per cent of water,=W'÷W W'. Example: See data page 14. W=2lb. W'=.18lb. Per cent =.18÷2.18=.0825 or 8.25 per cent. Determinations were made while the steam was being used at different rates, and for different heights of water in the boiler, but there is no uniform difference as shown by the results given on page .

Computation And Results:-

Computations were made as follows:- for any valve travel the cut-off was found from curve, for example, a travel of 1.5 in. corresponds to a cut-off of 25 per cent. The log for this test is given on page 13, (test 6) and the results are tabulated on page 18. The speed is shown to be 261 R.P.M. And the mean effective pressure was 21.7 pounds. Horsepower =P.xN.xK.=H.P. Where (P)=mean effective pressure, (N)=revolutions per minute, and (R)=LxA÷33000, where (L) =twice the length of stroke and (A)= area of piston. Area of cross section of piston rod must be deducted from (A) for crank end Then in this case

$$H.P. = \underset{21.7}{P} \times \underset{261}{N} \times \underset{.001495}{K} = 16.24$$

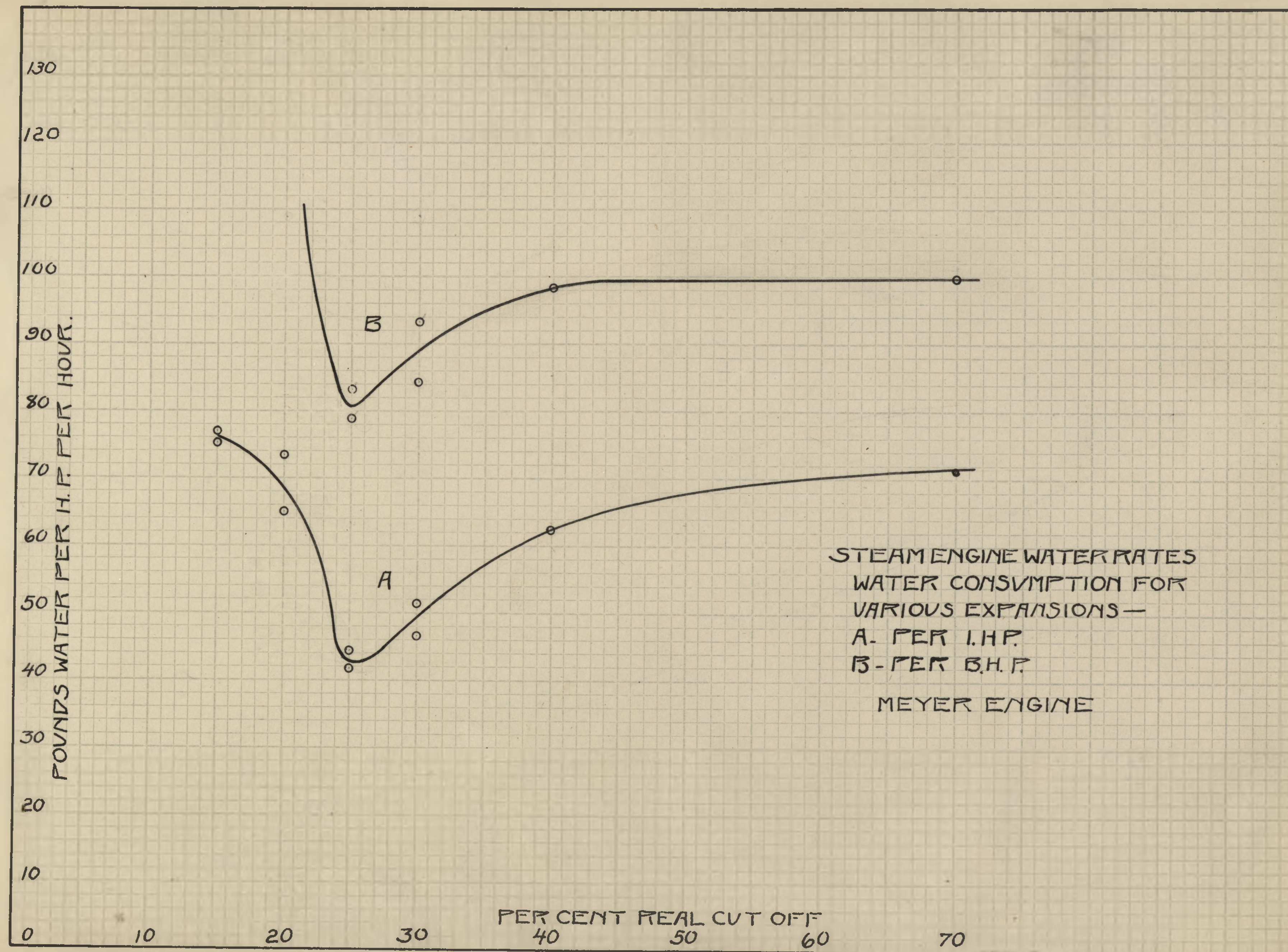
Brake horsepower equals $\frac{W \times S}{33000}$ =B. H. P. Where (W) equals net pressure that the brake exerted on the scales, and (S) equals circumference of fly wheel multiplied by the number of revolutions per minute, which in this case equals 70 x 14.39 x 261 =7.96. The other cards of the same experiment were solved in the same manner and tabulated as shown . The log sheet page 13 shows that the run was one half hour long, and that during that time, the water in the boiler dropped from 4.80 inches to 2.98 inches on the gage. From curve on page 21 we find that this difference in height on the gage indicates that 340 pounds of water was used. But from calorimeter tests made, it was found that 8.5 per cent water was carried with the steam in the average steam sample. Then 340 x .915 = 78.76 pounds. The results of the nine tests made are tabulated on pages 17, 18 and 19 , and minor tests are given on page 20. The water rates are very high, but are fairly uniform in the rate of change. The most economical point of cut-off is shown to be at about 26 per cent. On page 24 the curves are given for I. H. P. and B. H. P. The curve for I. H. P. is very abrupt in its changes, the drop for the economical point of cut-off being much more marked than it is in curve for the theoretical given on page .

The chief loss of heat in the early cut-off is due to initial condensation, and in this case the curve indicates that this loss decreases very fast as the cut-off increases, for the range of expansive effect, or higher final pressure, and probably in part to the evaporation of entertained water.

The hyperbolic curves drawn on the diagrams page 25 show that the expansive curve runs too high. Aside from this the steam distribution is fair. There was considerable negative lead for the early cut-offs but this diminished as the cut-off increased. From the observations taken it is clear that a material change for the latter could be affected; first, by a general adjustment of the bearings and stuffing boxes: second; by fitting rings to the piston valve: third; by passing the steam through a separator and covering the steam pipe.

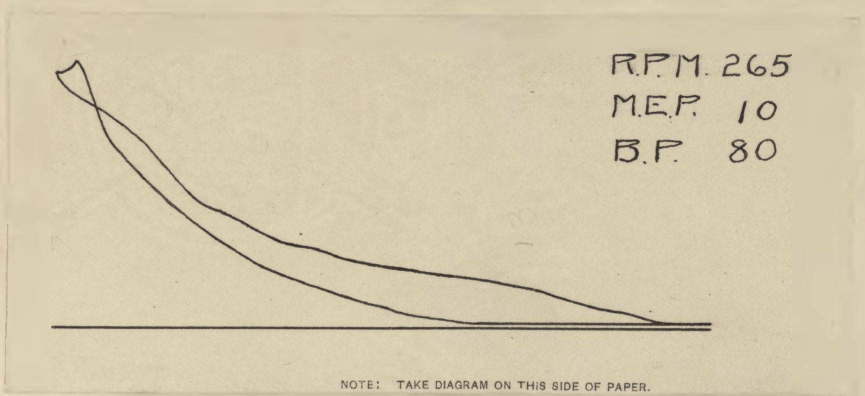
TESTS OF BALL ENGINE 8" x 10"

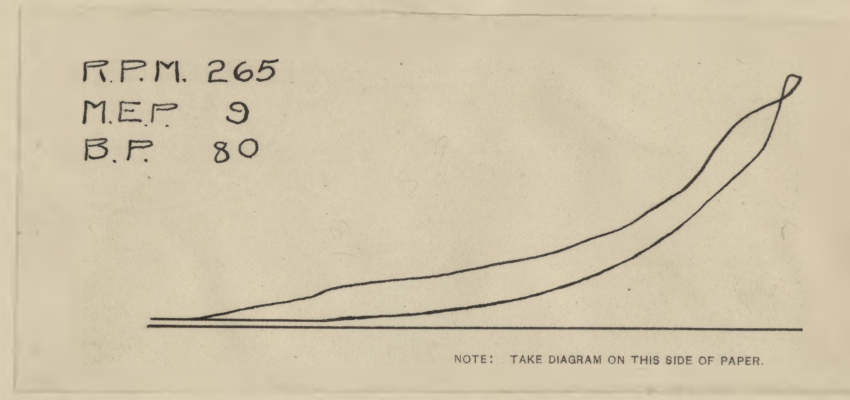
Description of Engine.

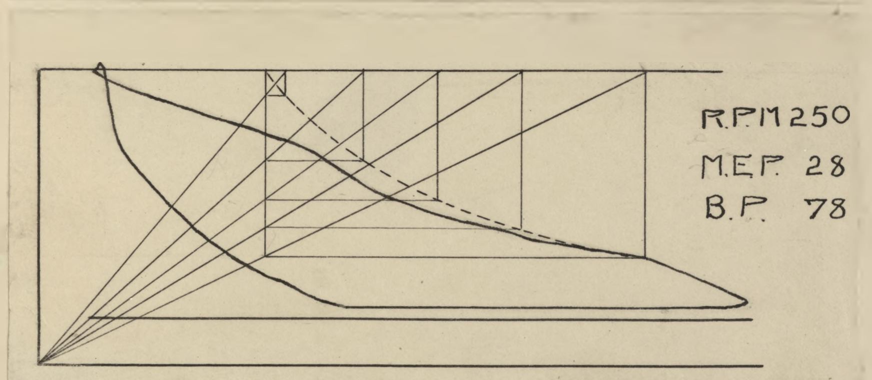

STEAM ENGINE WATER RATES
WATER CONSUMPTION FOR
VARIOUS EXPANSIONS —
A. PER I.H.P.
B - PER B.H.P.
MEYER ENGINE
POUNDS WATER PER I.H.P. PER HOUR.
PER CENT REAL CUT OFF
A
B
0
10
20
30
40
50
60
70
80
90
100
110
120
130

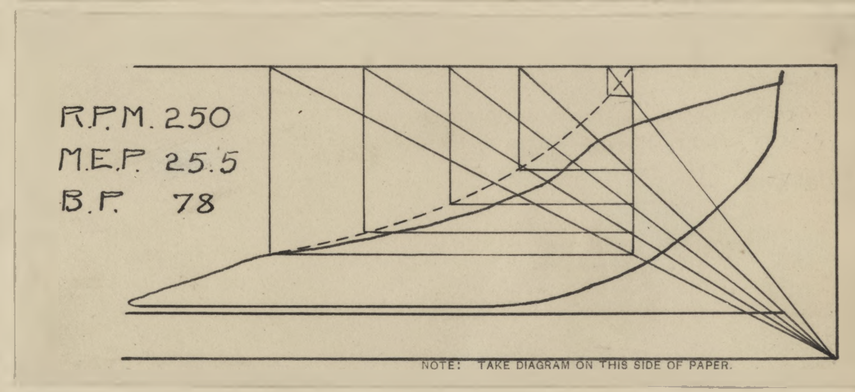
STEAM DISTRIBUTION, MEYER ENGINE AS TESTED, 8-20 AND 30 H.P.

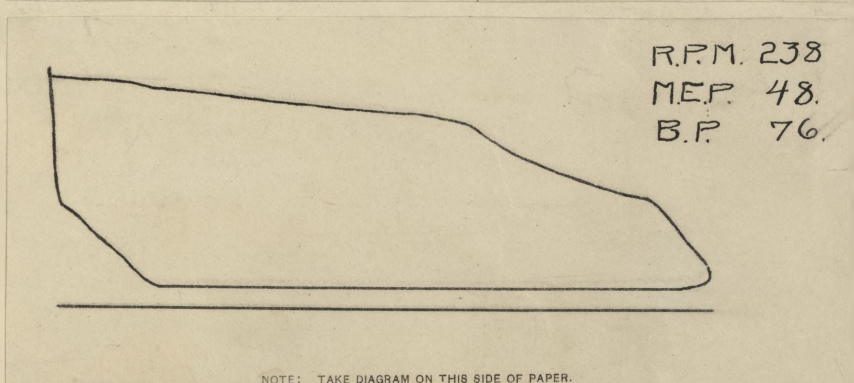
HEAD END   SCALE = 60   CRANK END

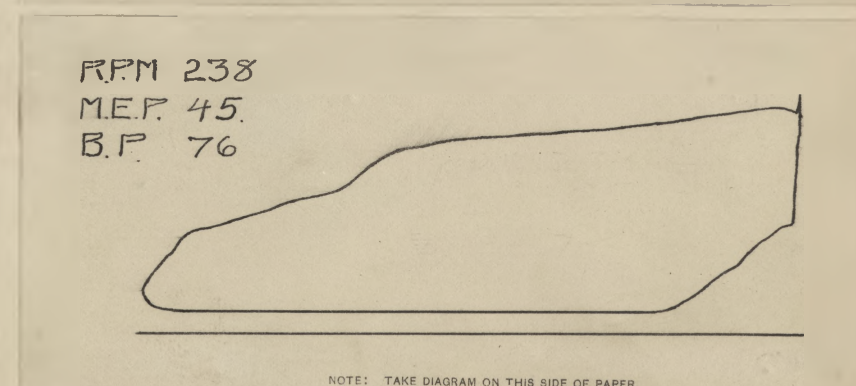


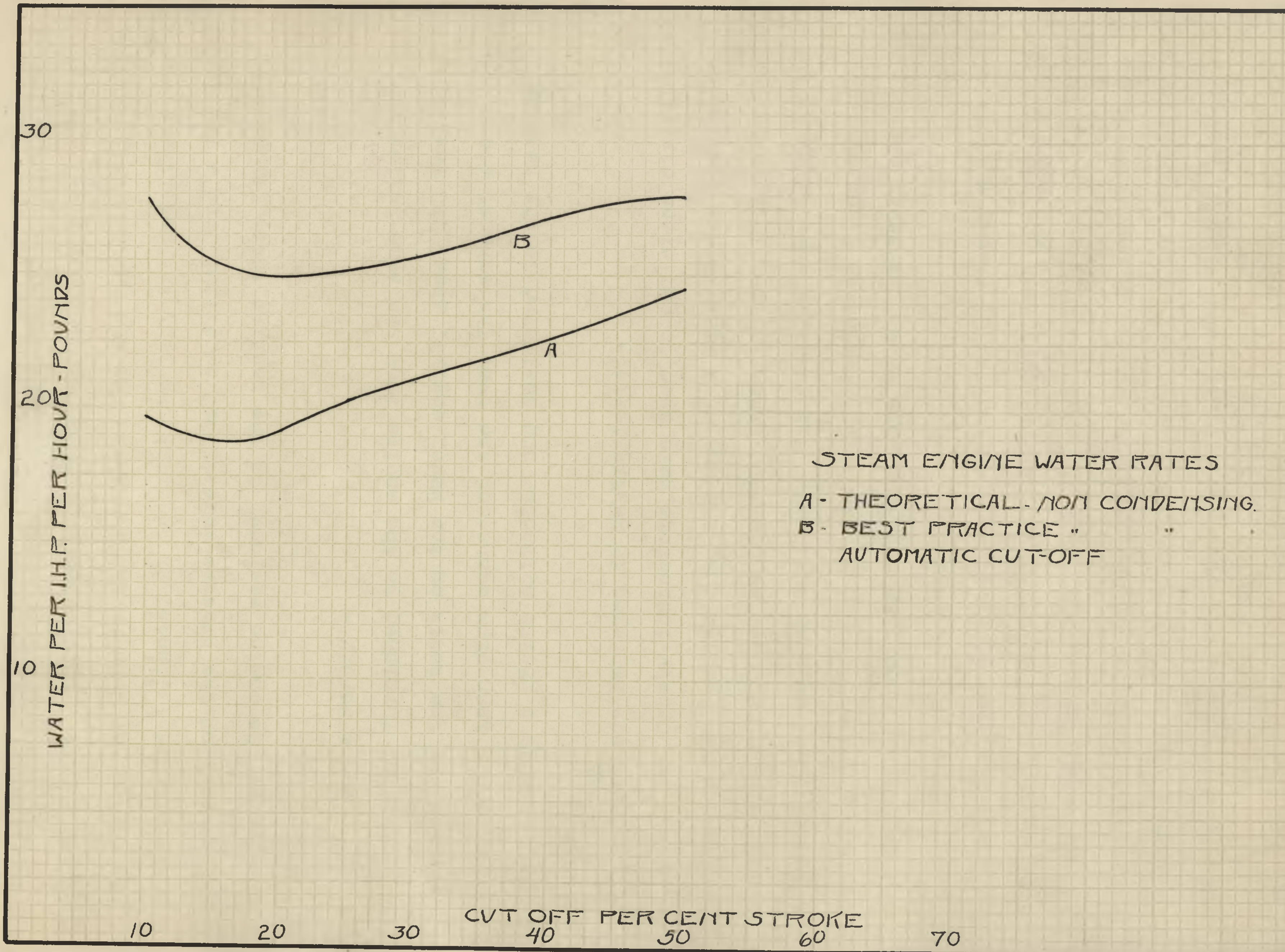











30
20
10
WATER PER I.H.P. PER HOUR - POUNDS
B
A
10
20
30
40
50
60
70
CUT OFF PER CENT STROKE
STEAM ENGINE WATER RATES
A - THEORETICAL - NON CONDENSING.
B - BEST PRACTICE " "
AUTOMATIC CUT-OFF

This is a high speed, non-condensing, automatic cut-off engine of the center crank pattern. Plate 2 shows the general connection. The engine was used to furnish power for the machine shops of the University of Illinois. At the time the test was made the governor and several of the brasses were in bad condition, and a few weeks afterward, the engine was sent to the machine shops for a general overhauling.

Steam Supply:-

Steam was furnished to the engine from the same boiler that was used for the tests on the Meyer engine. About 120 feet of jacketed 2.5 inch pipe connected the two. The exhaust steam was taken through a grease extractor and delivered to the heating system.

Methods Employed in Making Tests:-

Two 2 in. Crosby indicators were used to get steam distribution. Resistance was furnished by the use of a Prony brake bearing on a pair of platform scales. To find number of revolutions per minute a square speed counter was used. The readings were taken at the beginning and at the end of each experiment. All other apparatus and methods of operating were the same as on the Meyer engine.

Discussion of Results:-

The cards page 31 show the distribution of steam. The theoretical curves drawn dotted show that for the crank end the expansion is just about hyperbolic, while that of the head end is not. Since this condition is not common to both ends the raise in the expansion line can not be due to re-evaporation or evaporation of entertained water. From this we attribute the loss to leakage,

STEAM ENGINE WATER RATES

LOGS OF TESTS ON BALL AVTOMATIC ENGINE 8"x10"

TIME	SQVARE COVNTER	BOILER PRES.	WATER GAGE	VALVE TRAVEL	BRAKE LOAD LB.
TEST-1. 3-25-'98.					
9:31	0965	85	8.80	1.75"	5
9:38	-	85	-	"	"
9:45	-	84	-	"	"
9:55	-	84	-	"	"
10:01	1193	83	7.80	"	"
TEST-2. 3-25-'98.					
10:19	5185	75	6.40	1.83"	25
10:25	-	77	-	"	"
10:35	-	77	-	"	"
10:49	5009	80	5.10	"	"
TEST-3. 3-25-'98.					
11:03	0532	82	8.60	2.15"	60
11:15	-	81	-	"	"
11:20	-	77	-	"	"
11:26	-	76	-	"	"
11:33	0175	75	678	"	"

TIME	SQVARE COVNTER	BOILER PRES.	WATER GAGE	VALVE TRAVEL	BRAKE LOAD LB.
TEST-4-3-25-'98.					
11:47	5030	85	9.10	2.37"	122
11:55	-	82	-	"	"
12:02	-	82	-	"	"
12:10	-	81	-	"	"
12:17	4300	80	3.85	"	"
TEST-5-3-25-'98.					
12:50	5360	84	8.20	2.35"	106
12:57	-	83	-	"	"
1:05	-	83	-	"	"
1:12	-	83	-	"	"
1:20	4660	83	4.00	"	"
TEST-6-3-25-'98.					
1:35	8190	85	7.50	2.80"	220
1:42	-	83	-	"	"
1:50	-	83	-	"	"
1:56	-	83	-	"	"
2:05	2491	83	7.10	"	"

STEAM ENGINE WATER RATES

LOGS OF TESTS ON BALL AUTOMATIC ENGINE 8"x10"

TIME	SQUARE COUNTER	BOILER PRES.	WATER GAGE	VALVE TRAVEL	BRAKE LOAD LB.	TIME	SQUARE COUNTER	BOILER PRES.	WATER GAGE	VALVE TRAVEL	BRAKE LOAD LB.
TEST 7-3-25-98.						TEST-8-3-25-98.					
2:19	1075	82	5.20	2.23"	100	2:55	8100	75	4.80	2.06"	45
2:28	-	84	-	"	"	3:02	7768	77	-	"	"
2:35	-	83	-	"	"	3:10	-	78	-	"	"
2:40	-	84	-	"	"	3:18	-	78	-	"	"
2:49	0465	83	2.10	"	"	3:25	7768	80	3.36	"	"

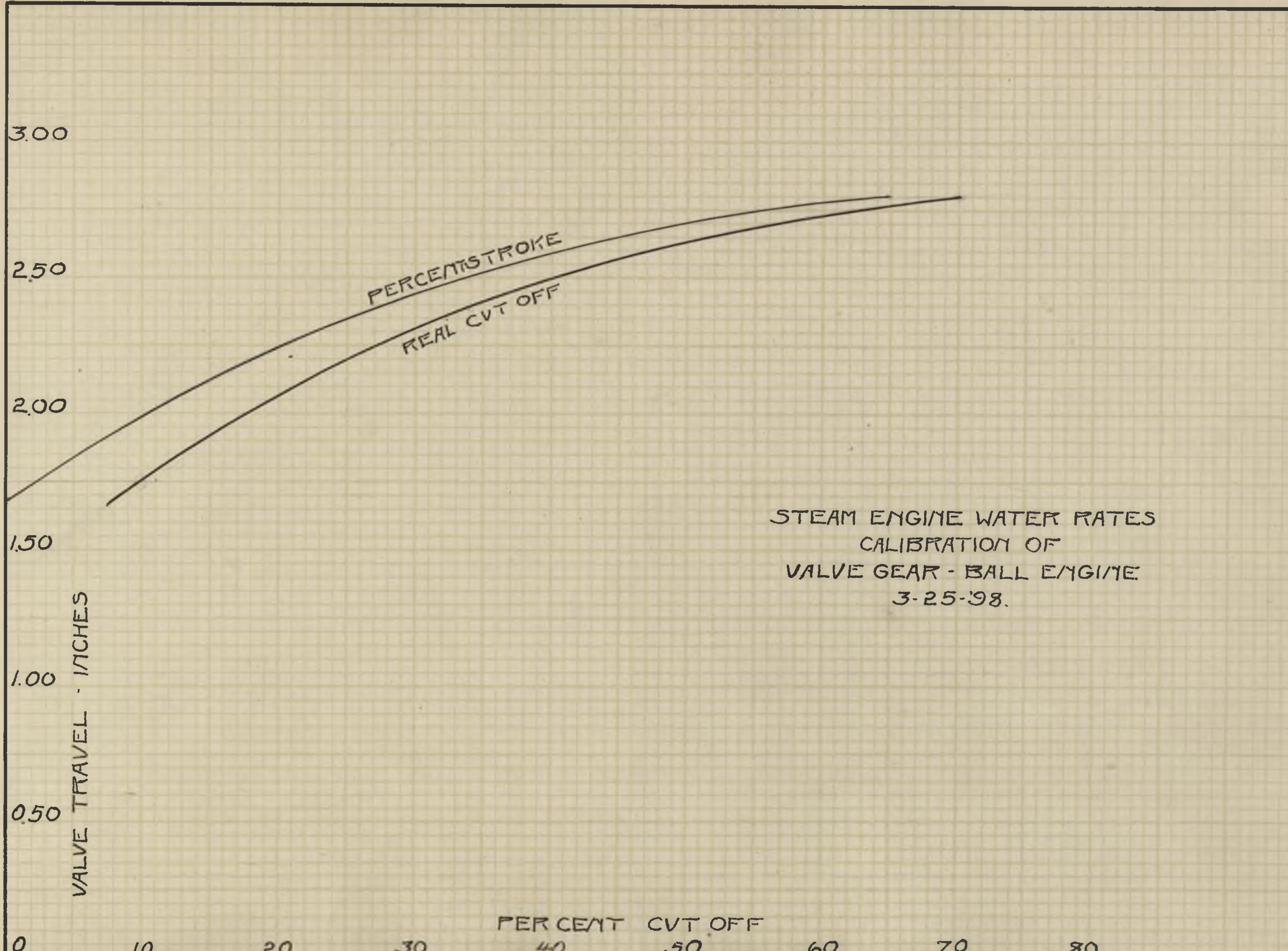
PRIMARY TESTS -

CALORIMETER

READING BOILER GAGE-IN.	CONDENSED STEAM LB.	ENTRAINED WATER LB.
8.50	4.00	.13
6.00	4.00	.14
3.00	4.00	.12
4.25	4.00	.15
8.00	4.00	.11
7.50	4.00	.13

CALIBRATION OF VALVE GEAR

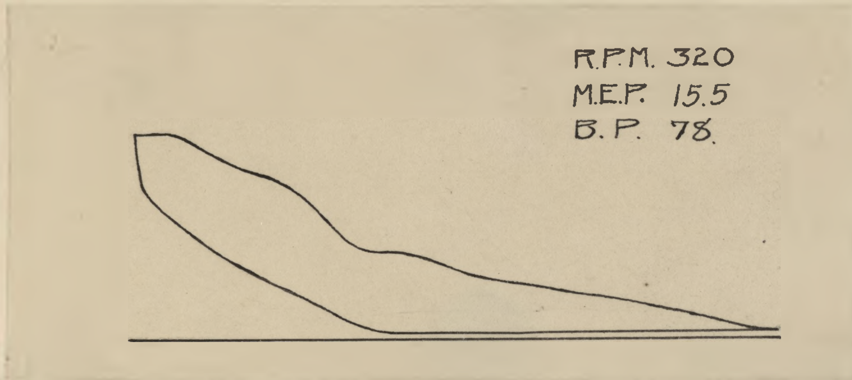
EX. No	CUT--OFF			VALVE TRAVEL
	HEAD	CRANK	MEAN	
1	.235"	.225"	.23"	1.75"
2	1.12"	1.08"	1.10"	2.00
3	2.08"	2.025	2.05"	2.25
4	3.44"	3.362	3.40"	2.50
5	5.56"	5.511	5.51	2.75

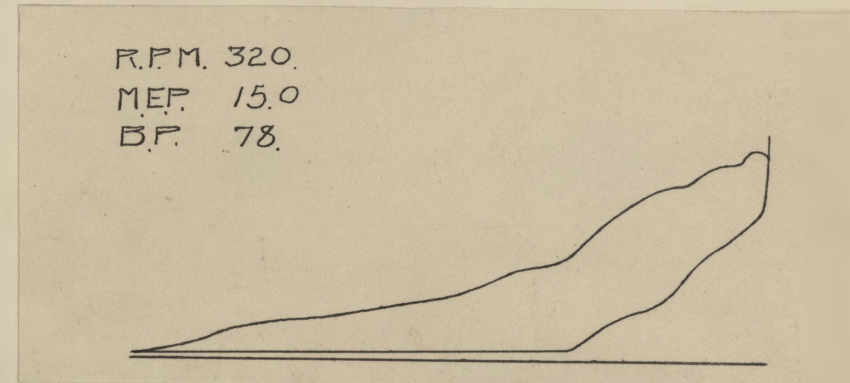


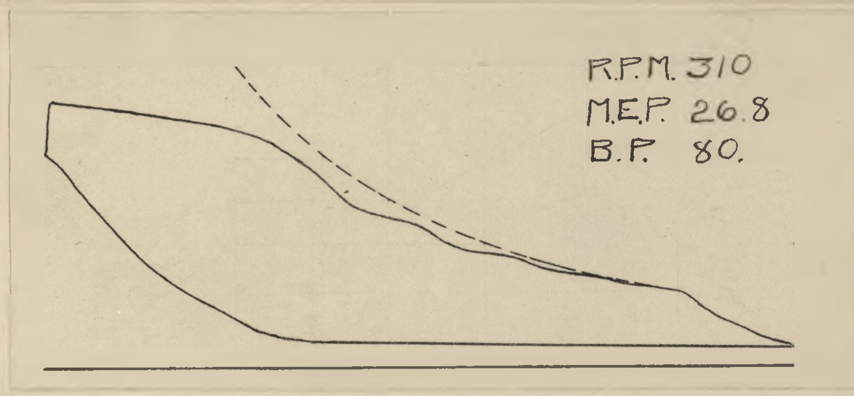
STEAM ENGINE WATER RATES
CALIBRATION OF
VALVE GEAR - BALL ENGINE
3-25-98.
PERCENT STROKE
REAL CUT OFF
VALVE TRAVEL - INCHES
PERCENT CUT OFF
3.00
2.50
2.00
1.50
1.00
0.50
0
10
20
30
40
50
60
70
80

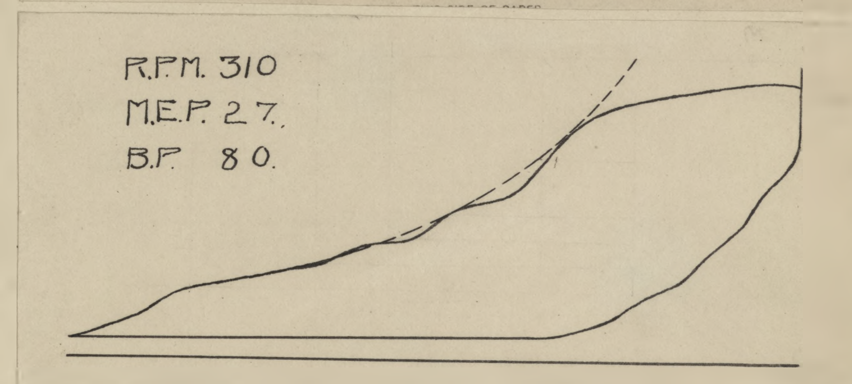
STEAM DISTRIBUTION, BALL ENGINE AS TESTED, 13-20 AND 30 I.H.P.

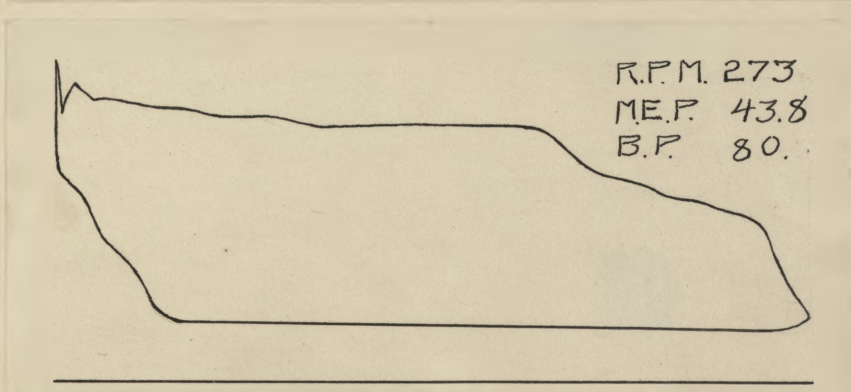
HEAD END SCALE=50 CRANK END

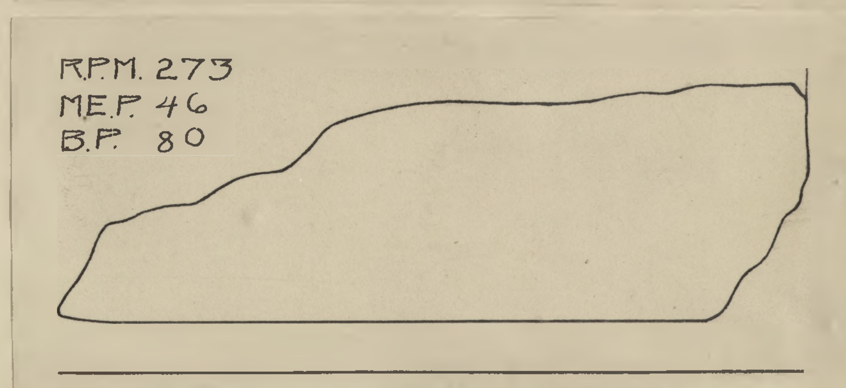


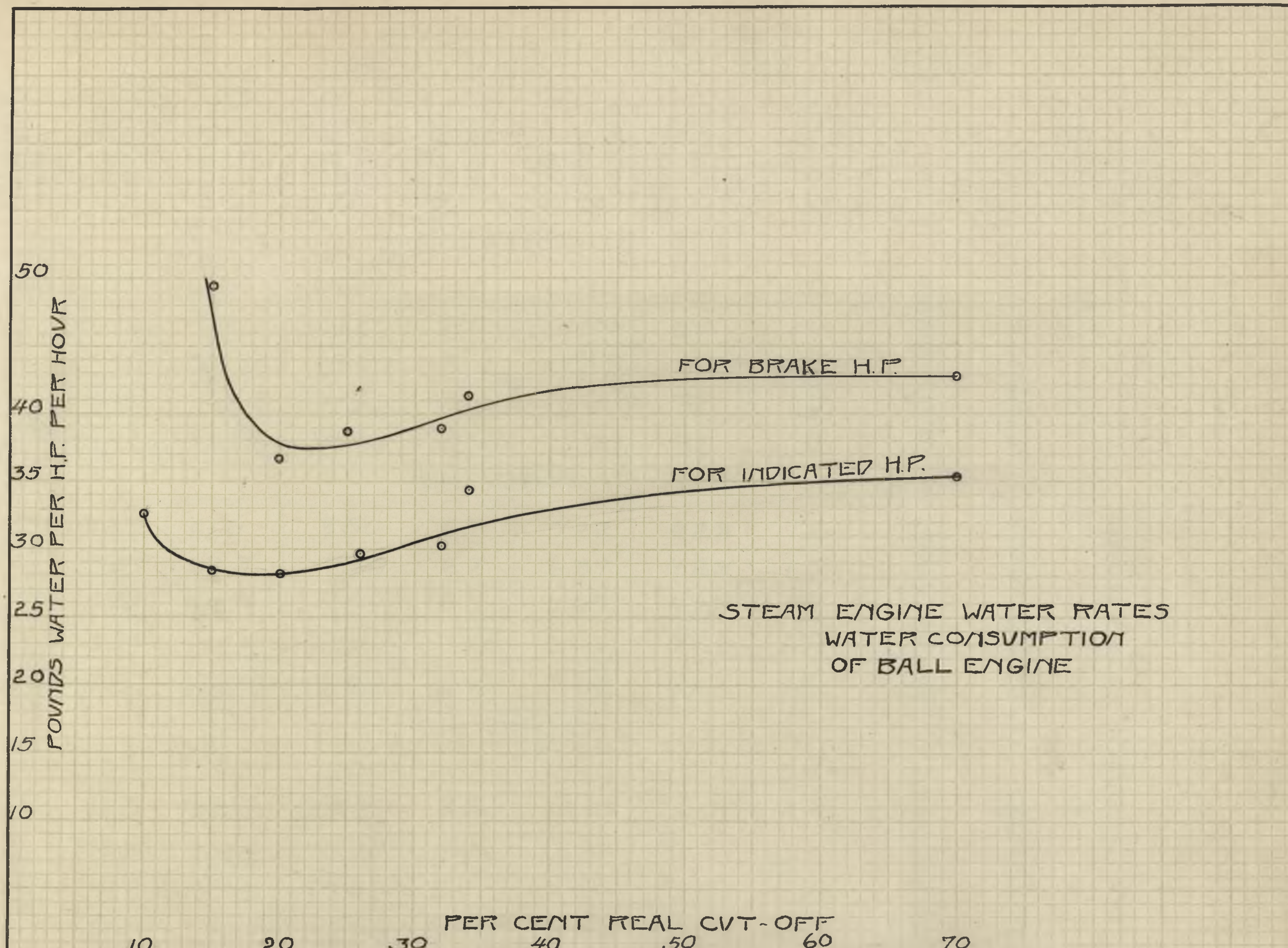











50
40
35
30
25
20
15
10
POUNDS WATER PER H.P. PER HOUR
FOR BRAKE H.P.
FOR INDICATED H.P.
STEAM ENGINE WATER RATES
WATER CONSUMPTION
OF BALL ENGINE
PER CENT REAL CUT-OFF
10
20
30
40
50
60
70

STEAM ENGINE WATER RATES
RESULTS OF TESTS ON BALL ENGINE

CARDS Nº	REV. PER. MIN.	INITIAL PRES	M.E.P.	FINAL PRES.	IND. HORSE POWER	BRAKE HORSE POWER	CUT OFF PERCENT STROKE +CL'R'NCE	WATER PER HOUR	WATER PER I.H.P. PER HOUR	WATER PER B.H.P. PER HOUR
				EXPERIMENT Nº 1						
1	340	81.0	4.00	2.0	3.40	MEAN .89	10	128.7 POUNDS	32.75 POUNDS	
2	340	74.0	5.25	2.5	4.46	.89	10			
3	340	75.5	5.00	2.0	4.25	.89	10			
4	340	80.0	4.25	4.0	3.61	.89	10			
MEAN	340	77.6	4.62	2.62	3.93	.89	10.			
				EXPERIMENT Nº 2						
5	327	61.0	8.50	6.5	7.22	4.28	15	207.88 POUNDS	28.4 POUNDS	48.42 POUNDS
6	327	62.5	7.50	6.7	6.37	4.28	15			
7	327	68.0	9.00	6.5	7.65	4.28	15			
8	327	67.0	9.50	7.25	8.05	4.28	15			
MEAN	327	62.12	8.62	6.73	7.32	4.28	15			
				EXPERIMENT Nº 3 - N.G.						
9	320	56.5	17.00	11.0	13.60	10.07	24	262.69 POUNDS	21.1 POUNDS	26.00 POUNDS
10	320	52.5	15.50	8.5	12.40	10.07	24			
11	320	54.5	15.25	8.0	12.20	10.07	24			
12	320	57.5	14.50	8.0	11.60	10.07	24			
MEAN	320	55.2	15.56	8.8	12.45	10.07	24			

STEAM ENGINE WATER RATES
RESULTS OF TESTS ON BALL ENGINE

CARDS No	REV. PER MIN	INITIAL PRES.	M.E.P.	FINAL PRES.	IND. HORSE POWER	BRAKE HORSE POWER	CUT OFF PERCENT STROKE + CL'R'NCE	WATER PER HOUR	WATER PER I.H.P. PER HOUR	WATER PER B.H.P. PER HOUR
EXPERIMENT No 4.										
13	309	72.5	30.75	20.5	23.90	19.70	34	820.78 POUNDS	34.52 POUNDS	41.57 POUNDS
14	309	74.0	31.50	20.0	23.72	19.70	34			
15	309	73.0	31.50	20.0	23.73	19.70	34			
16	309	–	–	–	–	–	–			
MEAN	309	73.1	31.25	20.16	23.78	19.70	34			
EXPERIMENT No 5.										
17	310	71.0	28.25	20.0	21.81	17.30	32	674.57 POUNDS	30.51 POUNDS	38.98 POUNDS
18	310	73.5	28.60	19.0	22.24	17.30	32			
19	310	72.0	28.75	19.5	22.21	17.30	32			
20	–	–	–	–	–	–	–			
MEAN	310	72.2	28.53	19.5	22.08	17.30	32			
EXPERIMENT No 6.										
21	273	75.0	41.85	40.0	30.14	25.48	70	1089.71 POUNDS	35.3 POUNDS	42.8 POUNDS
22	273	75.0	44.90	41.0	30.62	25.48	70			
23	273	75.0	45.50	41.0	31.86	25.48	70			
24	273	-	–	–	-	-	--			
MEAN	273	75.0	44.08	40.6	30.87	25.48	70			

STEAM ENGINE WATER RATES

RESULTS OF TESTS ON BALL ENGINE

CARDS No	REV. PER MIN.	INITIAL PRES.	M.E.P.	FINAL PRES.	IND. HORSE POWER	BRAKE HORSE POWER	CUT OFF PER CENT STROKE + CLR'NCE	WATER PER HOUR	WATER PER I.H.P. PER HOUR	WATER PER B.H.P. PER HOUR
EXPERIMENT No 7										
25	313	72.0	27.00	19.0	20.16	16.69	26.	614.51 POUNDS	29.81 POUNDS	38.8 POUNDS
26	313	71.5	26.75	19.0	20.93	16.69	26			
27	313	71.0	28.25	19.0	21.77	16.69	26			
28	–	–	–	–	-	-	–			
MEAN	313	71.5	27.33	19.0	20.95	16.69	26.			
EXPERIMENT No 8										
29	322	51.5	13.00	9.0	10.45	7.59	20	280.91 POUNDS	28.12 POUNDS	36.7 POUNDS
30	322	55.0	13.50	8.0	10.85	7.59	20			
31	322	57.0	12.50	8.0	10.05	7.59	20			
32	322	59.5	12.00	7.75	9.64	7.59	20			
MEAN	322	55.5	12.75	8.09	9.99	7.59	20			

STEAM ENGINE WATER RATES
RESULTS OF TESTS AND CALIBRATIONS. BALL ENGINE

CALIBRATION OF VALVE GEAR

EX. No	VALVE TRAVEL	MEAN CUT OFF-IN.	PER CENT STROKE	PER CENT STROKE + CLEARANCE	TABLE FROM CURVE: REAL CUT OFF	TABLE FROM CURVE: VALVE TRAVEL
1	1.75"	.23"	2.3	10	10%	1.75"
2	2.00"	1.10	10.4	17.6	15	1.83"
3	2.25	2.05	20.3	27.3	20	2.06"
4	2.50	3.40	34	40.3	30	2.31"
5	2.75"	5.51	55.6	63.3	40	2.49"

WATER RATES
MEAN RESULTS-FROM CURVE

CUT OFF	INITIAL PRES.	M.E.P.	FINAL PRES.	WATER PER I.H.P. PER HR.	WATER PER BHP PER HR.
10%	78.	4.6	2.6	32.7	
15 "	62	8.6	6.7	28.4	48.42
20 "	55	13.0	8.0	28.1	36.7
26 "	71	27.0	19.0	29.81	38.8
32 "	72	28.5	19.0	30.50	38.98
34	73	31.2	20.0	34.52	41.57
70	75	44.08	40.0	55.30	42.80

CALORIMETER TEST

EX. No	WATER GAGE READING ON BOILER	QUALITY OF STEAM
1	8.50"	96.9%
2	6.00"	96.6
3	3.00"	97.2
4	4.25"	96.3
5	8.00"	97.5
6	7.50"	96.9
MEAN		96.9

36

STEAM ENGINE WATER RATES

DETERMINATION OF CLEARANCE

BALL ENGINE

VOLUME OF CYLINDER IN EXCESS OF STROKE TERMINATION - HEAD -	6.49 CV. IN.
" " " " " " " " CRANK -	6.87 " "
" " EACH PORT	34.0 " "
CLEARANCE EQUALS	502.6 ÷ 40.71 = 8.1 % STROKE

MEYER ENGINE

WATER USED	1.70
PISTON DISPLACEMENT	.95"
CLEARANCE	.95 × 12 = 7.9 % STROKE

and as the curve runs too high at the outer end the leak must be at the valve. The distribution otherwise is fair. It will be noticed that the upper cards are shorter than the others. This is due to the fact that during the test the pantagraph reducing motion was thrown from the engine, and several bolts broken. In replacing them the adjustment was changed, It was not noticed at the time but however it makes no material difference in the results. Logs of the tests made are given on pages 28 and 29. The computations were made in the same way as those of the Meyer engine. The rates tabulated on pages 33 to 36 show marked improvement in the Ball engine over those of the Meyer engine. The curve of rates page 28 shows a fair performance. The most economical point of cut-off for I. H. P. is shown to be at about 19 per cent, while for B. H.P. it is about 22 per cent. The best rate is 28.12 pounds of water per I. H. P. per hour, and was obtained at 20 per cent cut-off. Experiment number 3 gives a much lower rate, but it has been discarded as there was evidently some error of observation. These rates are not especially good but are fairly satisfactory for an engine of this class. If the engine were in the best condition we might expect to get about 3 or 4 pounds less water per I. H. P. per hour, or about 25 pounds per I. H. P. per hour at one fourth real cut-off.

To those interested in the subject of steam engine performance the following list of references will be of some value.

THE PROMISE AND POTENCY OF HIGH PRESSURE STEAM.
Trans. A. S. M. E. 1896.
Illustrated by the triple and quadruple expansion, experimantal engines of Sibley College, Cornell University.
Water rates are given for the different rates of expansion and for different pressures. Results of experiments are illustrated graphically.

THE ECONOMICAL GOVERNORING OF STEAM ENGINES.
By John S. Raworth.
Engineering Magazine November 1897.
A brief on governors with a discussion and graphical illustration of engine performance for different rates of expansion.

CONDITIONS EFFECTING WATER CONSUMPTION.
By R. A. Thurston.
Thurston's Manuel of The Steam Engine Part 2.
Short discussion of steam engine performance illustrated by curves and data.

THE QUANTITY OF STEAM WHICH MIGHT BE AND WHICH IS USED.
By Chas. A. Smith.
Steam Engine Practice.
A theoretical discussion illustrated by curves and tables, also reports of experiments.

STEAM AND WATER CONSUMPTION. By R. A. Thurston.
Engine and Boiler Trials.
Tables of water rates and methods of determining the consumption of any engine.

THEORETICAL WATER CONSUMPTION. By Peabody.
Thermodynamics of The Steam Engine.
Theoretical discussion of water rates and a series of reports of tests on engines of water consumption.

WATER RATES AT DIFFERENT POINTS OF CUT-OFF.
By Rose.
Results of Tests of Engines to Determine Water Rates.

STEAM ENGINE WATER RATES. By Willian Kent.
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Tables of theoretical and practical rates of steam comsumption.

ECONOMY TRIALS OF A NON-CONDENSING STEAM ENGINE, SIMPLE, COMPOUND AND TRIPLE. By P.W.Willans
Proceedings of Institution of Civil Engineers, Vol. 93.
Exhaustive discussion illustrated graphically.

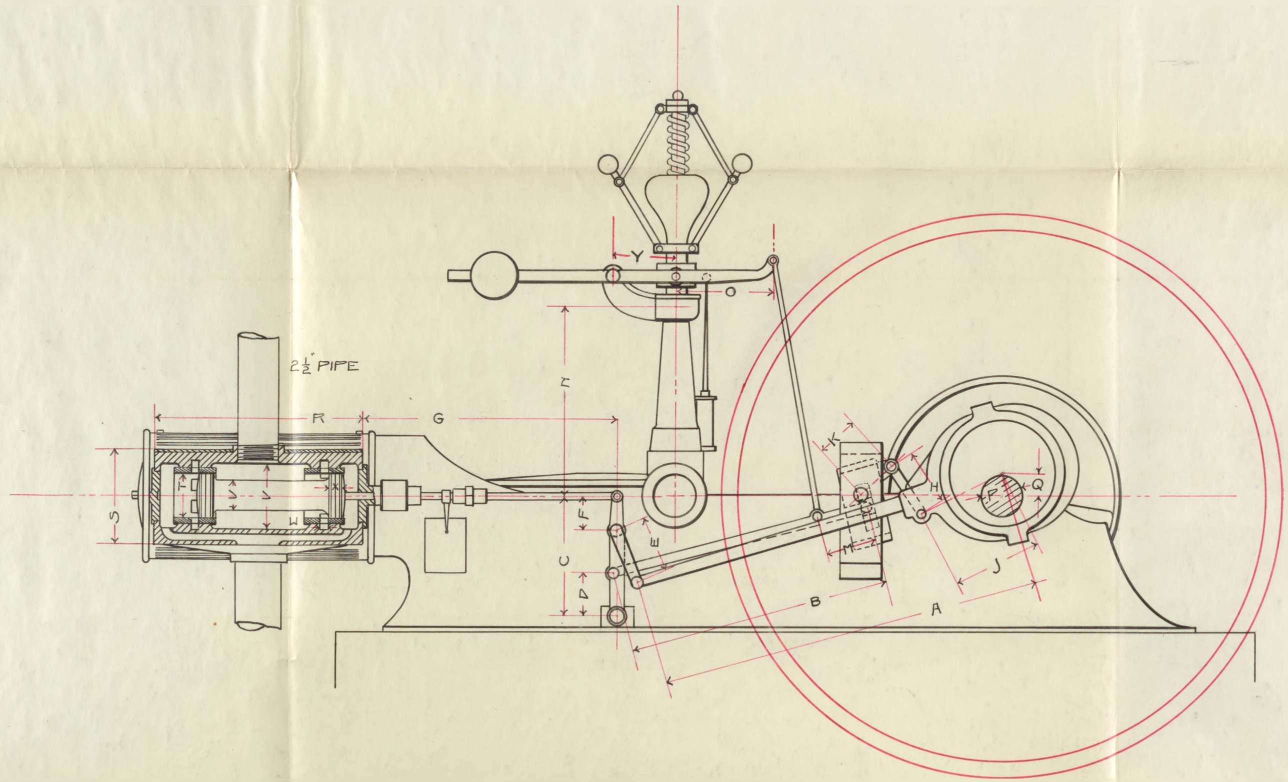


TABLE OF DIMENSIONS CYLINDER - 8"×12"					
A	3'0"	J	0'7"	R	1'8"
B	2'11"	K	0'4½	S	0'9"
C	0'11"	L	1'10"	T	0'4"
D	0'5¾	M	0'5"	V	0'2¾"
E	0'5¼	N	1'6"	V	0'5"
F	0'3"	O	0'9	W	0'⅝"
G	2'0"	P	0'4"	X	0'1¼
H	0'6	Q	0'2½	Y	0'6"

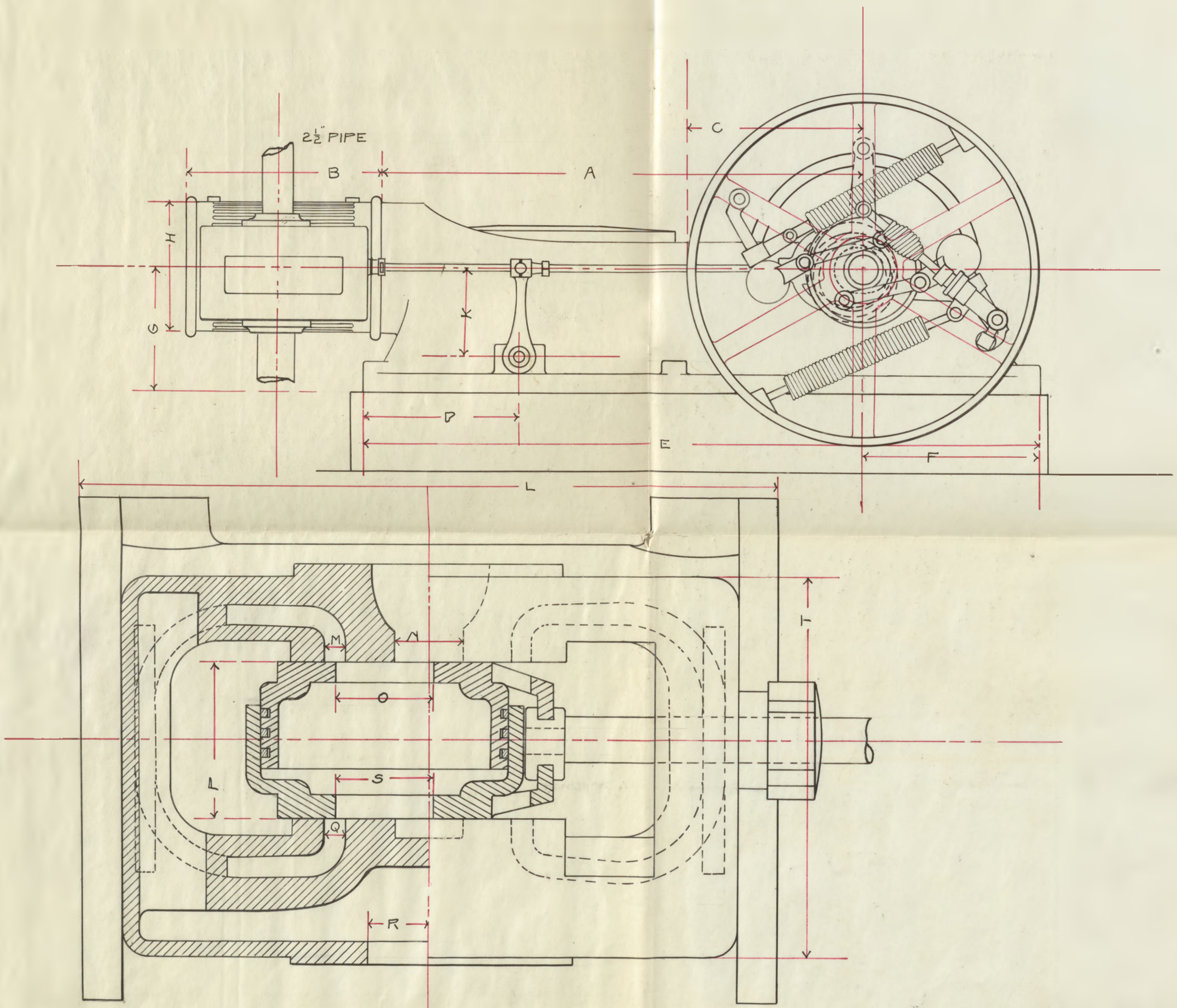
THESIS
STEAM ENGINE WATER RATES
VALVE GEAR
MEYER AUTOMATIC ENGINE
SCALE = $\frac{1}{8}$

JAN. 22- 1898 PLATE - 1.

W. J. Hommers

TABLE OF DIMENSIONS
CYLINDER - 8" × 10"

A	4'-1"	G	12 5/8"	O	2 5/8"
B	2'-3 3/4"	H	13 1/4"	P	4"
C	18"	K	9"	Q	1/2
D	18	L	17 3/4"	R	1 1/2"
E	5-8"	M	1/2"	S	2 5/8"
F	18"	N	1 3/4	T	9 5/8



THESIS
STEAM ENGINE WATER RATES

BALL AUTOMATIC ENGINE

SCALE 1/8 AND 1/2

MAY 1. 1898. PLATE 2.

M. J. Hammers